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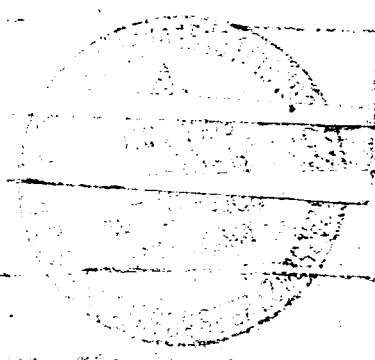
# **A STUDY OF HYDROGEN SLUSH AND/OR HYDROGEN GEL UTILIZATION**

## **CONTRACT NAS 8-20342**

(FOLLOW-ON)

### **FOURTH QUARTERLY PROGRESS REPORT**

**PREPARED FOR  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA**



**CRYOGENIC STAGE PROGRAMS**

REPRODUCED BY  
NATIONAL TECHNICAL  
INFORMATION SERVICE  
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SPRINGFIELD, VA. 22161

**LOCKHEED MISSILES & SPACE COMPANY / SUNNYVALE, CALIFORNIA**



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**C. W. KELLER  
PROJECT MANAGER**



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## FOREWORD

This report pertains to work accomplished by the Lockheed Missiles & Space Company during the fourth quarter of a continuing contract program entitled, "A Study of Hydrogen Slush and/or Hydrogen Gel Utilization." The current work is being performed as a follow-on to Contract NAS8-20342. The most recent modification to the contract, which is now being executed, provides for an extension of the contract performance period from fourteen to eighteen months.

This study is being performed for the National Aeronautics and Space Administration (NASA) under the technical cognizance of Mr. A. L. Worlund of the Fluid Thermal Systems Branch of the Propulsion and Vehicle Engineering Laboratory (R-P&VE-PTF) at the George C. Marshall Space Flight Center.

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Section 1  
INTRODUCTION AND SUMMARY

1.1 PROGRAM OBJECTIVES

This program is being conducted under modification to the previously completed contract of the same number and title. The primary objectives of this follow-on program are to (1) analytically and experimentally verify that triple-point liquid and slush hydrogen can be successfully applied to a practical flight-type tankage system, and (2) analytically investigate subsystem design effects and compare performance for application of liquid and slush hydrogen to an additional vehicle and mission of current interest.

1.2 TASK SUMMARY

Part A of this program is a three-task analytical and subscale experimental study that satisfies the first program objective. Approximately ninety percent of the total program effort is being directed toward this study. Part B is a single-task analytical study of a S-IVC manned Mars flyby mission vehicle that satisfies the second program objective. It constitutes the remaining ten percent of the total effort.

1.3 PROGRESS SUMMARY

During this quarterly reporting period, installation and checkout activities were completed to provide the slush manufacturing and transfer facilities needed for this program, fabrication and welding operations were continued on the slush propellant storage dewar, and the slush test apparatus was installed in the vacuum test chamber at the Santa Cruz Test Base site. Subsequent to the installation of the test apparatus, all related plumbing, instrumentation, controls, and wiring were installed. Two 19-pin cryogenic feedthrough connectors

developed by the Deutsch Company under the Lockheed Independent Development program for use in this contract test program, were thermally shocked with liquid nitrogen and liquid hydrogen and then leak tested. No leakage was detected after five thermal cycles using an Atlas mass spectrometer with a rated sensitivity of  $10^{-11}$  std cubic centimeters of helium per second. A third connector that contains coaxial feedthrough pins is scheduled for immediate testing and installation in the slush test apparatus. Approximately 90 percent of the slush test instrumentation and controls were checked out with excellent results during this period.

All analytical work was completed during this quarter pertaining to the S-IVC Manned Mars Flyby Vehicle Application Study. Significant results and conclusions are summarized in this report. A draft of the final report for this part of the contract work is being prepared for immediate submittal. It was found in this study that substantial payload gains could be achieved with use of subcooled and slush hydrogen in the S-IVC flyby vehicle. For example, the payload spacecraft weight obtained with use of triple-point liquid hydrogen was 192,250 lb, compared with 180,600 lb obtained with use of atmospheric-saturated liquid. This is a gain of approximately 6.5 percent. The payload spacecraft weight that resulted from use of 50-percent slush hydrogen was 193,450 lb, or a corresponding gain of approximately 7.1 percent. These gains are somewhat less on a percentage basis than those previously determined for the S-IVB/LASS mission vehicle, primarily because use of high-performance insulation and other related vehicle modifications significantly increase the hydrogen storage capability of atmospheric-saturated liquid hydrogen in the S-IVC stages.

## Section 2

### TECHNICAL PROGRESS

#### 2.1 PART A. SUBSCALE EXPERIMENTAL PROGRAM

During this quarterly reporting period, work was continued under Task 2 to (1) install and checkout the slush manufacturing and transfer facility systems at Lockheed's Santa Cruz Test Base, (2) fabricate, assemble, proof-test, install, and check out the slush propellant storage dewar with its associated equipment, and (3) install and check out the slush test apparatus. Figure 2-1 shows the relationship of existing and added facility equipment, Lockheed independent development equipment, and program equipment. This task is now nearing completion, except that the slush propellant storage dewar and the test apparatus will require approximately one more month of effort. Details regarding progress during this period, and the current status of each of these hardware systems, is contained in the following paragraphs.

##### 2.1.1 Slush Manufacturing and Transfer Facilities

Installation and checkout of the slush manufacturing and transfer facilities are now complete. Figure 2-2 is a photograph showing the slush manufacturing dewar (left center), the helium heat exchanger (foreground), the flight simulator vacuum chamber (upper right), and many of the connecting lines, valves, and fittings required to manufacture and transfer slush during the planned test program. The vacuum-pumping line and a portion of the hot water heat exchanger required to heat the cold hydrogen vapor can also be seen (on the left). The installation was only partially completed when this photograph was taken, but has since been completed. Slush nitrogen was manufactured and transferred with excellent results during the final checkout process.

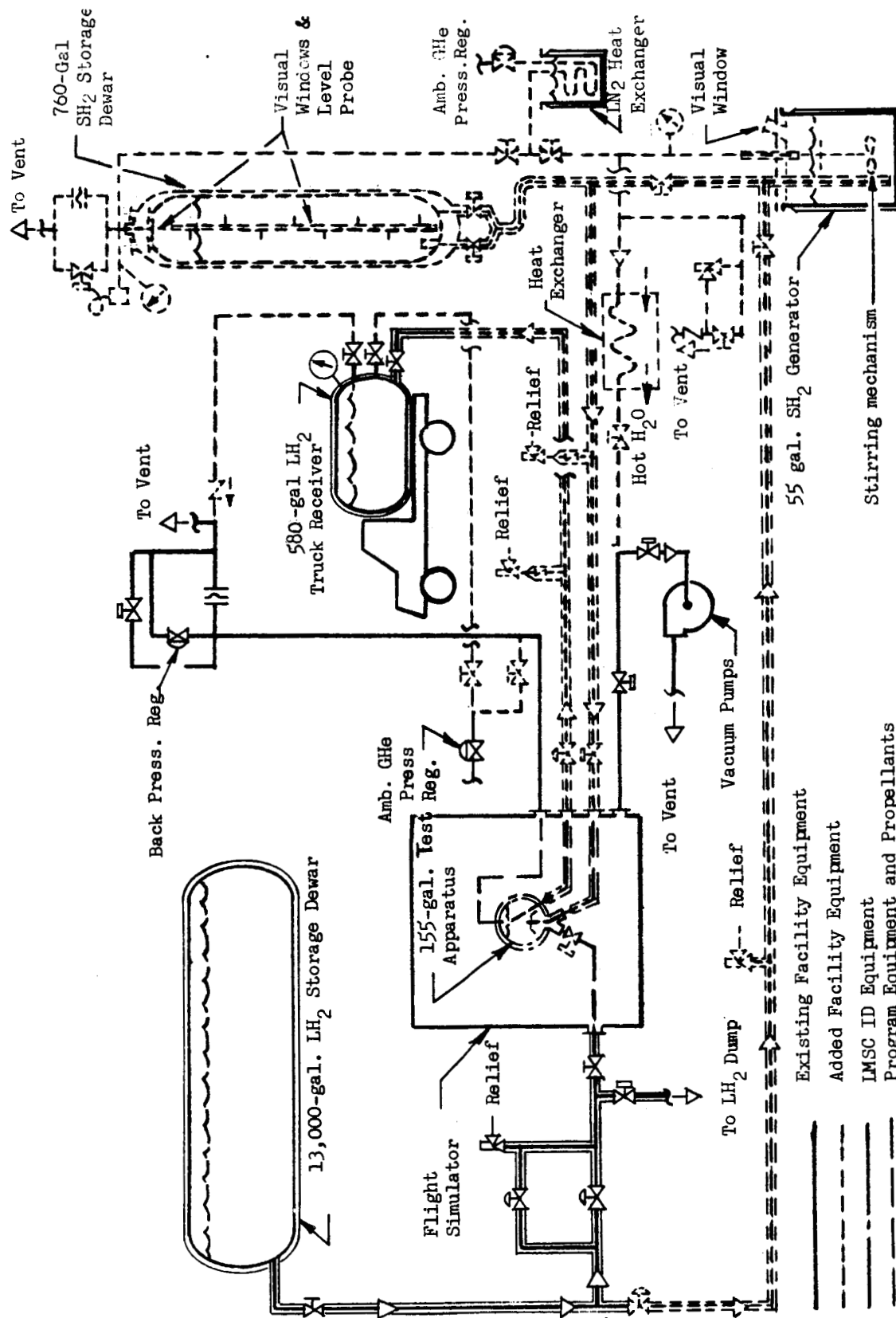


Fig. 2-1 Slush Hydrogen Manufacturing, Transfer, Storage, and Test Systems

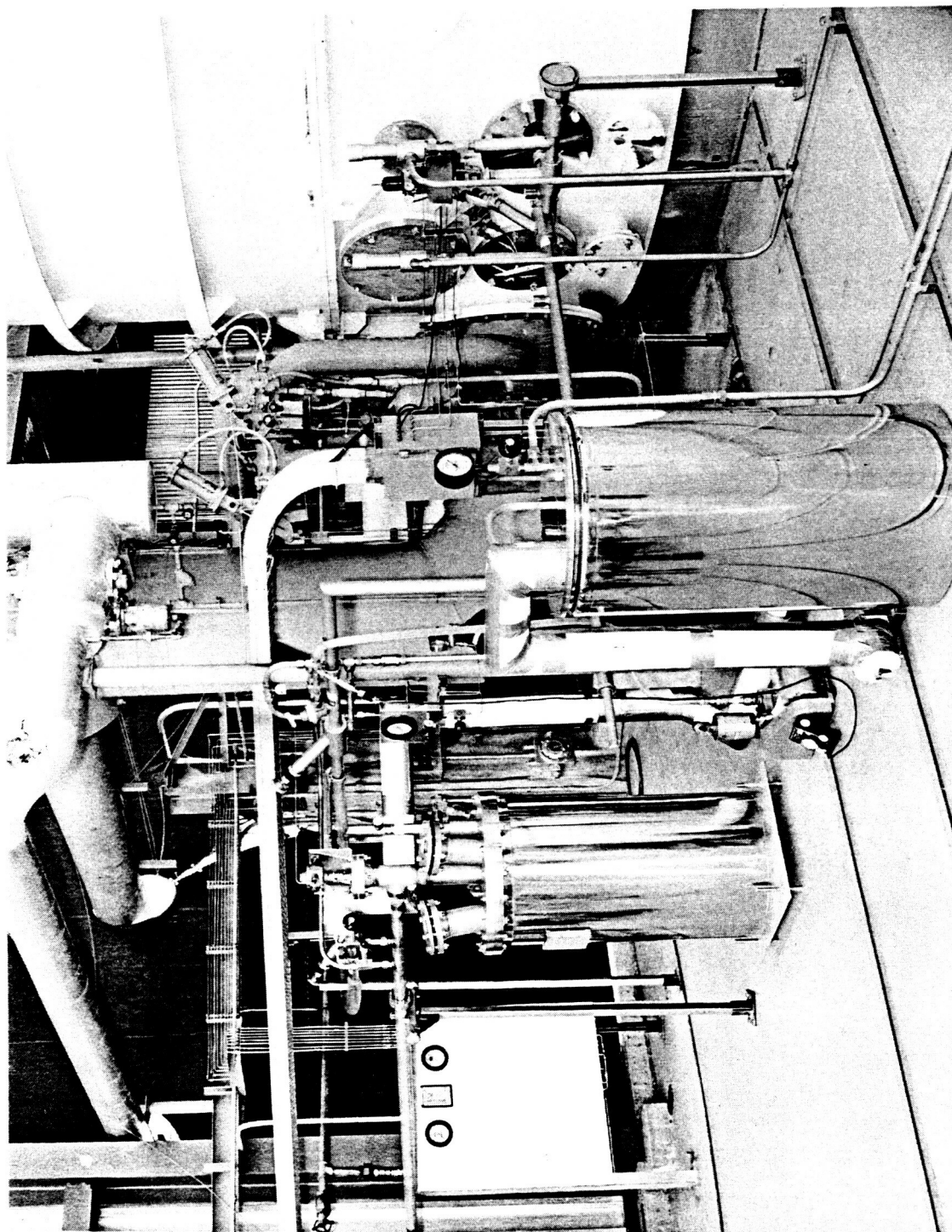


Fig. 2-2 Photograph of Slush Manufacturing and Transfer Facilities

Details of the manufacturing dewar cover, fill and drain line, vacuum-pumping line, foam insulation plug, and slush stirring mechanism are shown in Fig. 2-3. The stirring mechanism is driven by an externally-mounted air motor (which can be seen in Fig. 2-2) through a rotating vacuum-seal.

Work is currently in progress to install instrumentation and controls in the remotely-located blockhouse. These will be used to monitor and control slush transfer, vacuum chamber pumpdown, and other required test operations. Layout of the control valve console is shown in Fig. 2-4.

Two additional hardware components are currently being procured to prepare the slush manufacturing and transfer facilities for contract test operations. A new Stokes vacuum pump is scheduled for delivery in approximately four weeks to replace one of the two existing vacuum pumps that is no longer suitable for use. The new pump is rated at 300 cfm, compared to 250 cfm for the pump being replaced. The total rated vacuum-pumping capability of the two pumps that will now be used to manufacture slush for the contract program is 580 cfm, or approximately 220 cfm per square foot of liquid-vapor interface area in the manufacturing dewar. The second hardware component, which is scheduled for immediate delivery and installation, is a remotely-operated, quick-acting shutoff valve for the vacuum-pumping line. This valve will replace the manually-operated valve now located in the system, and will be operated by a push-button control located adjacent to the slush manufacturing dewar. Its installation and use will greatly streamline and simplify the slush manufacturing process.

#### 2.1.2 Slush Propellant Storage Dewar

Fabrication and assembly of the dewar shell components were delayed during this reporting period due to required maintenance operations on the welding machine used for the longitudinal cylinder seams. Figure 2-5 shows the outer vacuum-jacket cylinder after completion of the longitudinal seam weld. External

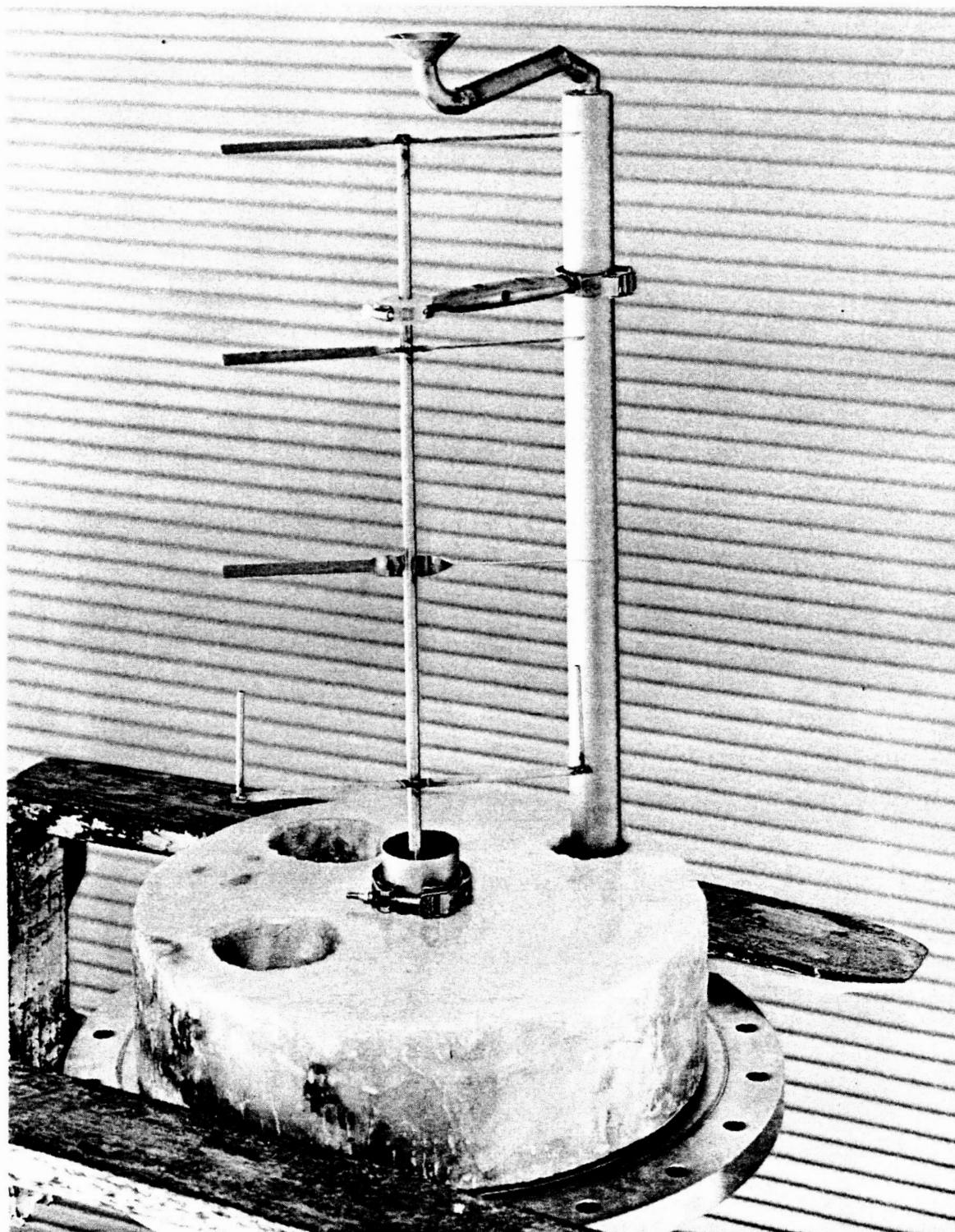


Fig. 2-3 Photograph of Slush Manufacturing Dewar Internal Components



Fig. 2-4 Photograph of Slush Test Control Console Located in the Blockhouse

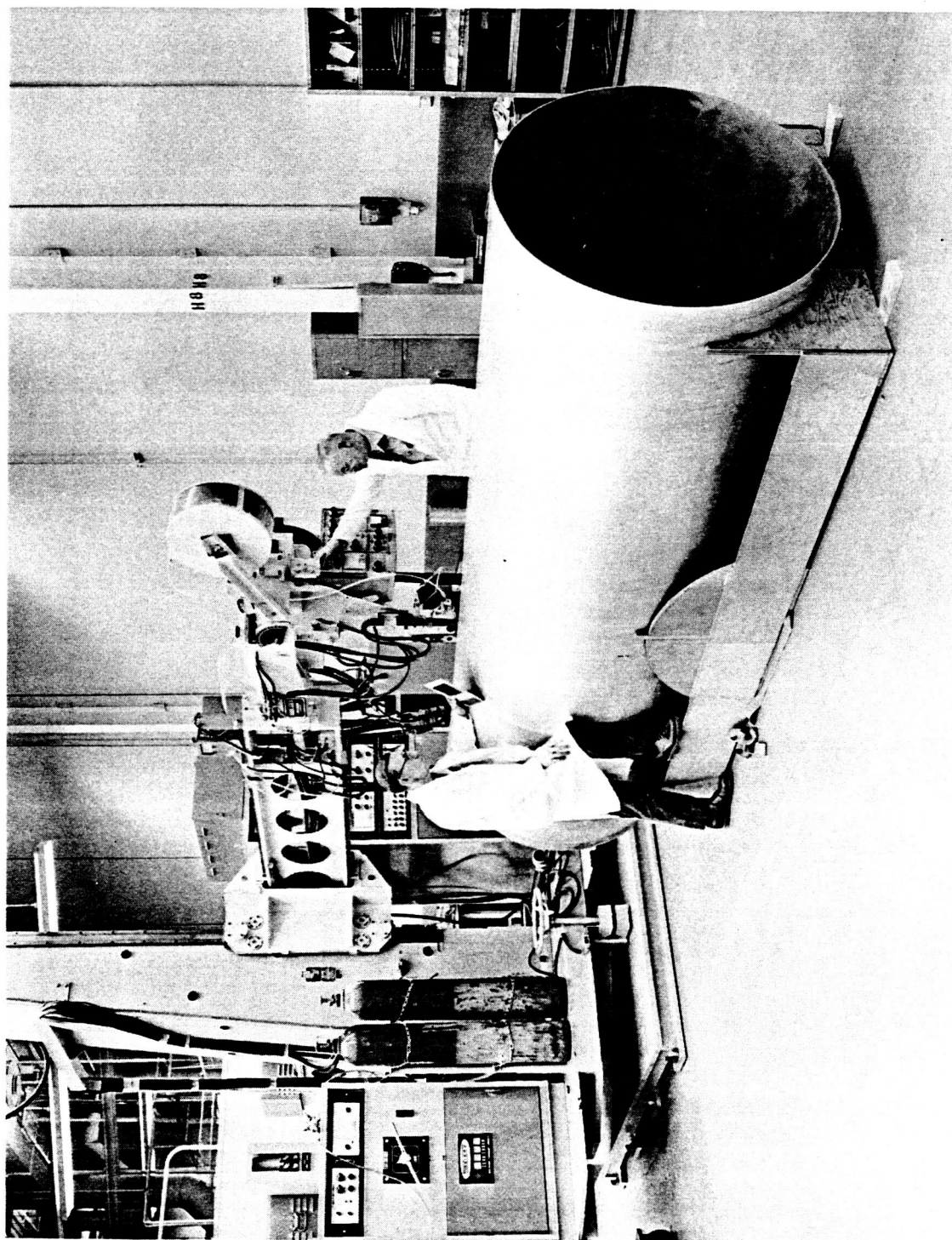


Fig. 2-5 Photograph of Dewar Outer Shell Cylinder During Welding Operations

stiffening rings have now been welded to this cylinder, and the longitudinal weld for the inner pressure vessel cylinder was recently completed. Concurrent welding operations to assemble the inner and outer hemispheres and the mating flanges are also now in progress. Proof-test of the inner vessel shell is scheduled for approximately 17 May. Completion of the dewar final assembly, and delivery to the test site, is scheduled for approximately 7 June. Satisfactory achievement of these two schedule milestones will permit initiation of the contract tests beginning on approximately 21 June.

### 2.1.3 Slush Test Apparatus

The 41.5-in.-diameter test tank apparatus is now installed in the flight simulator vacuum chamber at the SCTB test site. All plumbing systems, and test instrumentation and control components and wiring, were installed and connected during this reporting period. Figures 2-6 and 2-7 show the final pre-fit mockup and assembly of the tank and apparatus performed just prior to shipment of this hardware from the manufacturing facility to the test site.

Two of three required electrical feedthrough connectors, recently developed by the Deutsch Company under the Lockheed Independent Development program, were thermally shocked with liquid nitrogen and liquid hydrogen and then leak tested during this reporting period. One of these feedthrough connectors is shown in Fig. 2-8. No leakage of GHe could be detected after five thermal cycles using a mass spectrometer capable of detecting leakage at a rate of  $10^{-11}$  std cc/sec. The third feedthrough connector is scheduled for immediate thermal shock and leakage tests.

The first two feedthrough connectors tested have subsequently been installed in the test apparatus. All instrumentation and control wiring are now completed, and instrumentation checkouts have been satisfactorily completed.

Figures 2-9 and 2-10 show the basic apparatus installed in the vacuum chamber at the test site. Details of the submersible mixer systems and other in-tank instrumentation and control components can be seen in the photographs of Figs. 2-11 and 2-12.

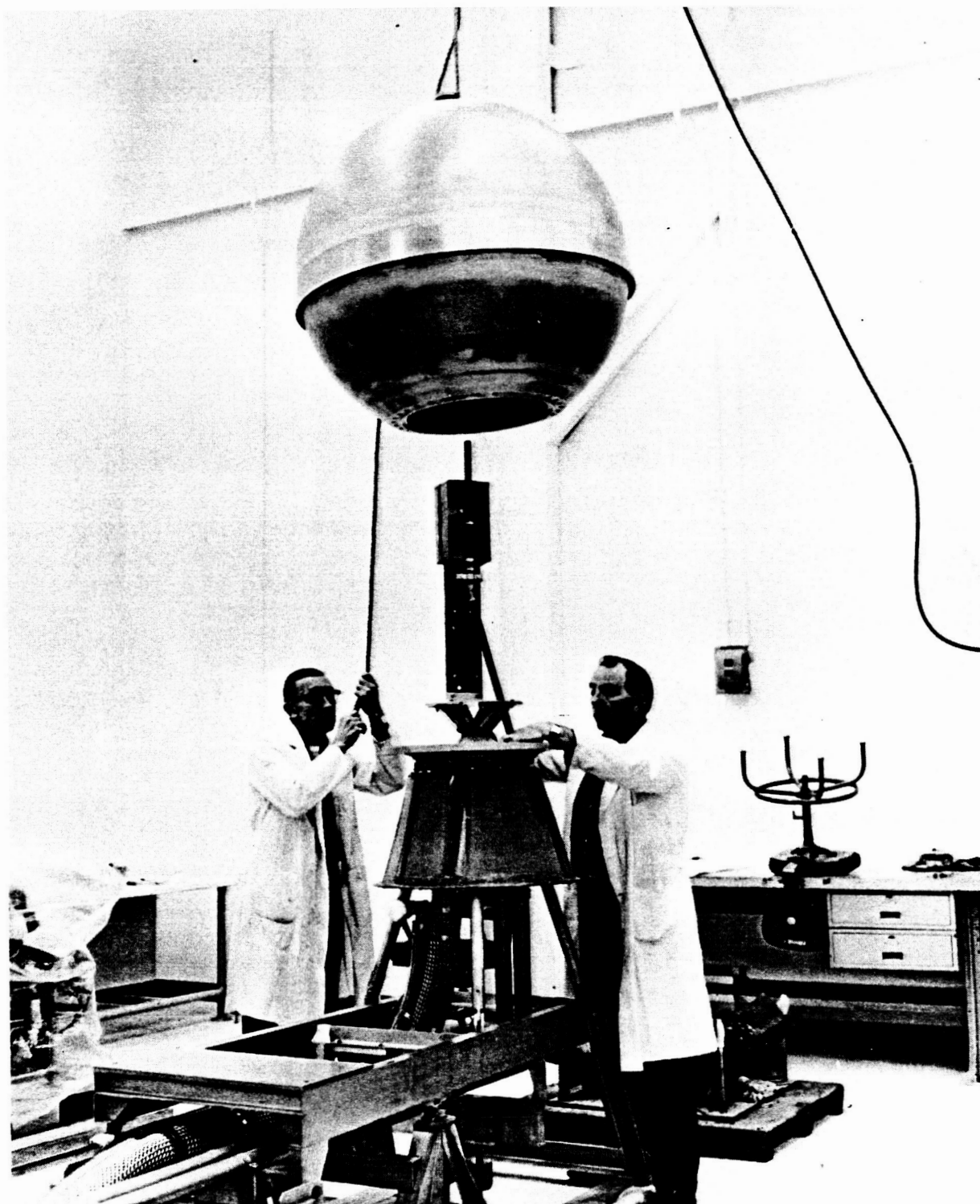


Fig. 2-6 Photograph of Slush Test Apparatus During Installation of the 41.5-Inch Diameter Tank

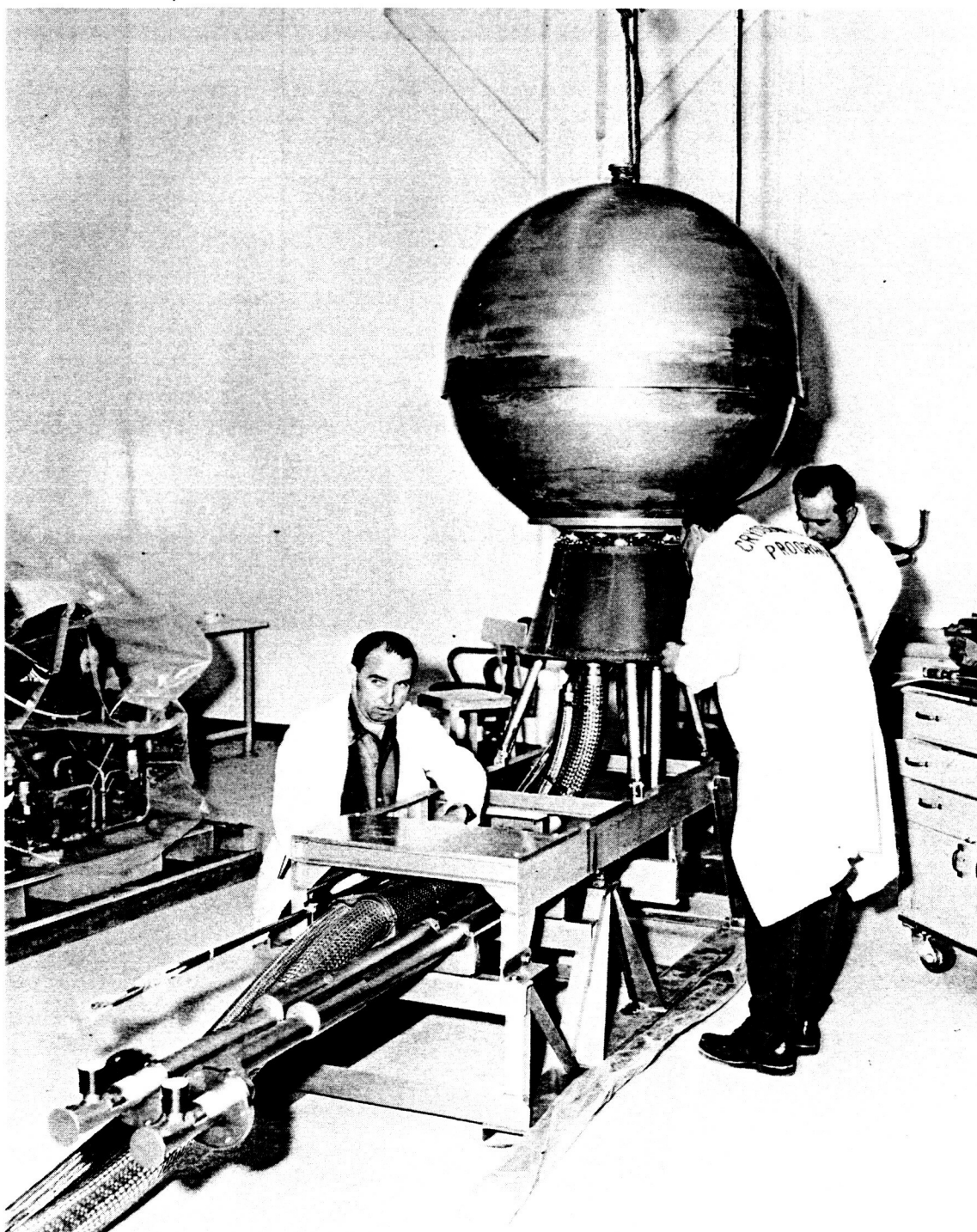


Fig. 2-7 Photograph of the Slush Test Apparatus After Prefit Assembly

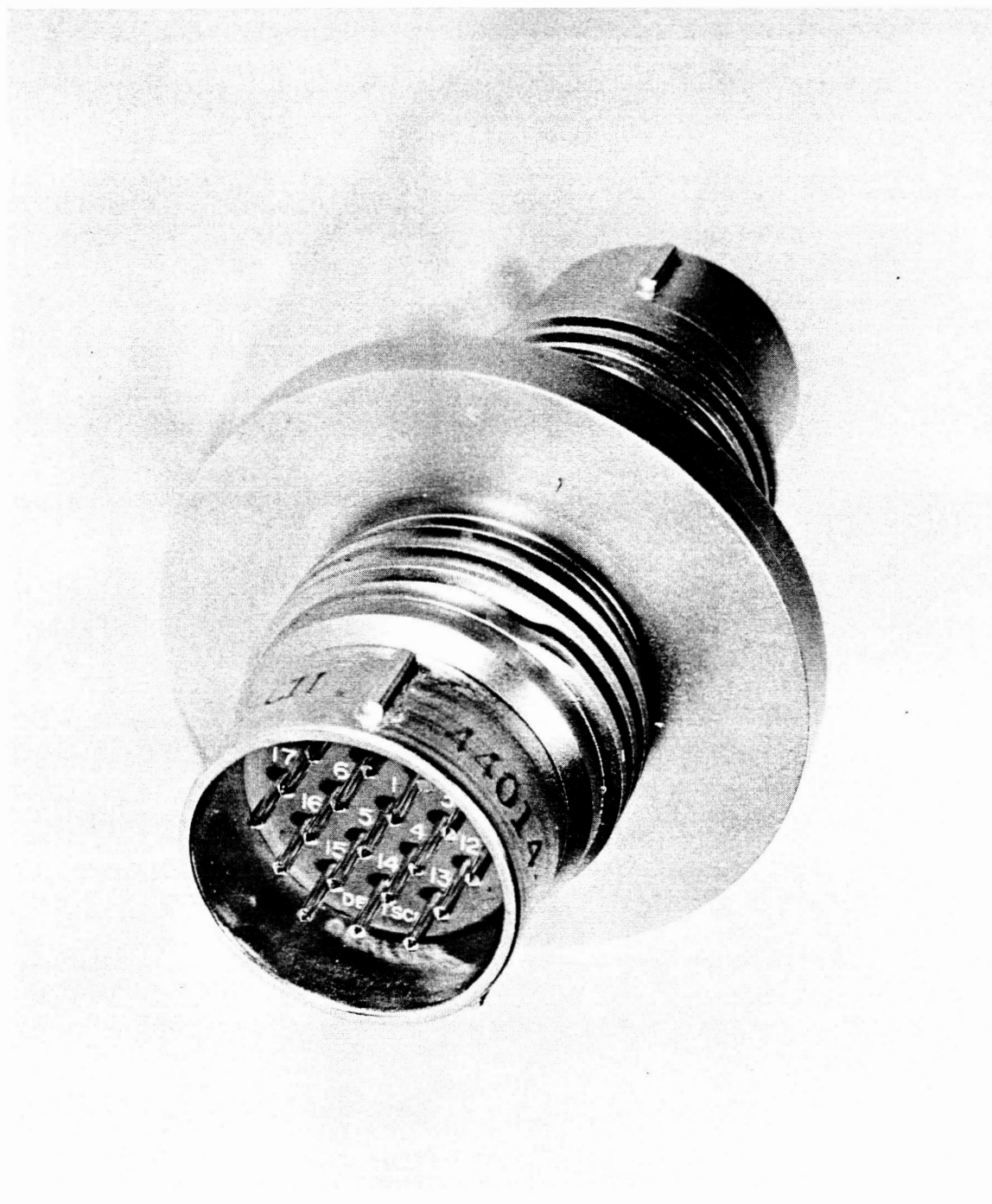


Fig. 2-8 Photograph of Recently-Developed Cryogenic Feedthrough Connector

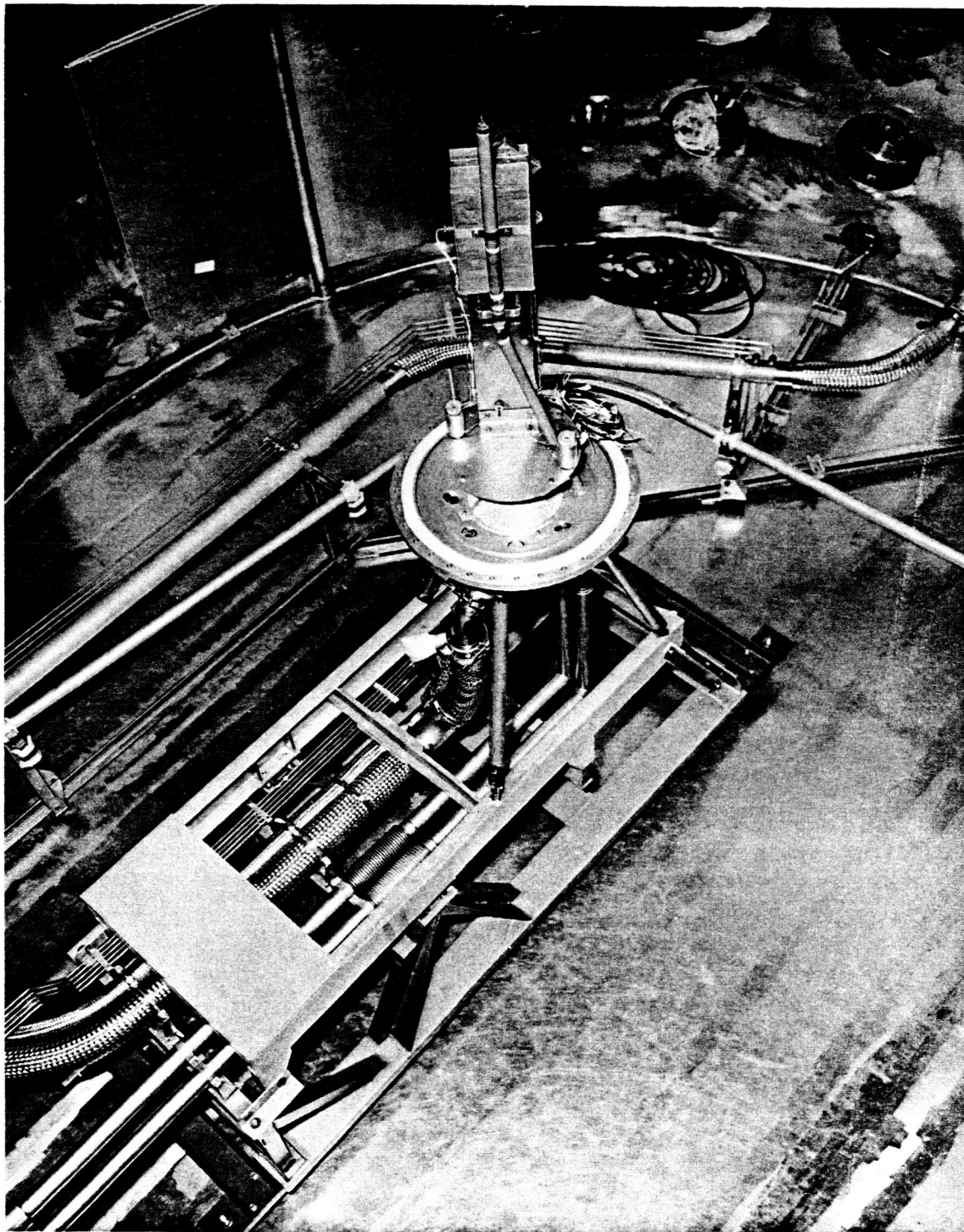


Fig. 2-9 Photograph of Slush Test Apparatus Installed in Flight Simulation

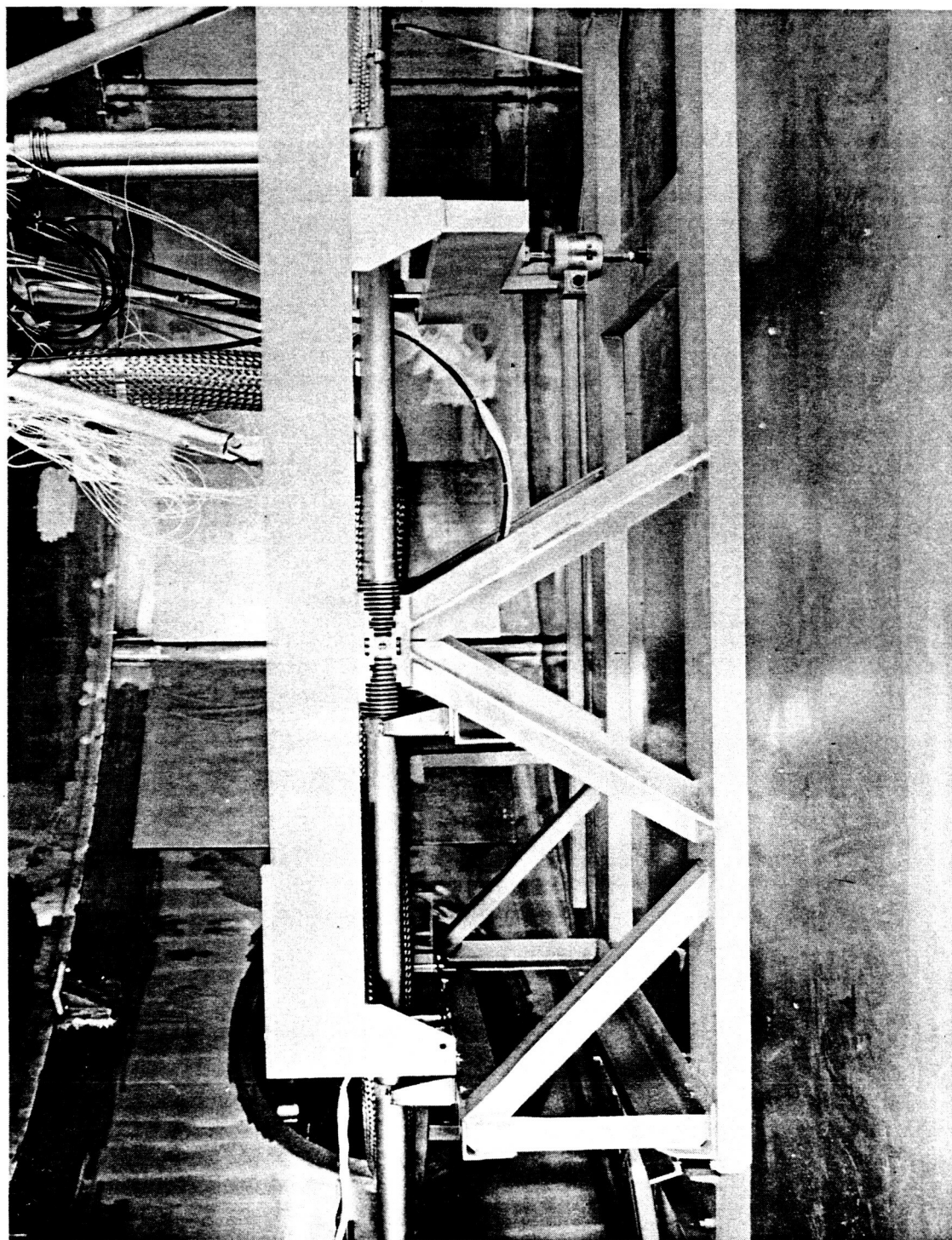


Fig. 2-10 Photograph of Slush Test Apparatus Counter-Balanced Propellant Weighing System

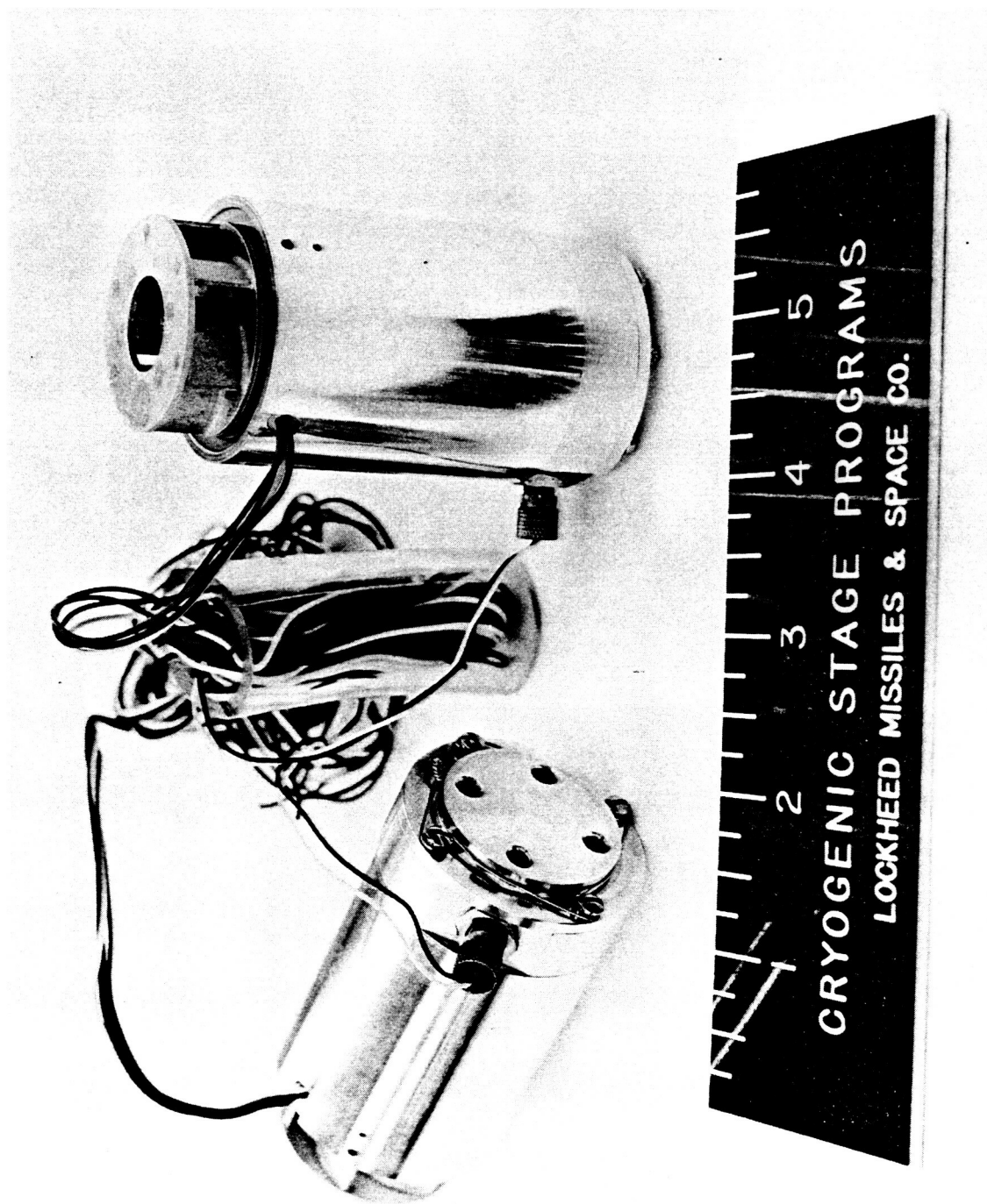


Fig. 2-11 Photograph of Submersible Propellant Mixers

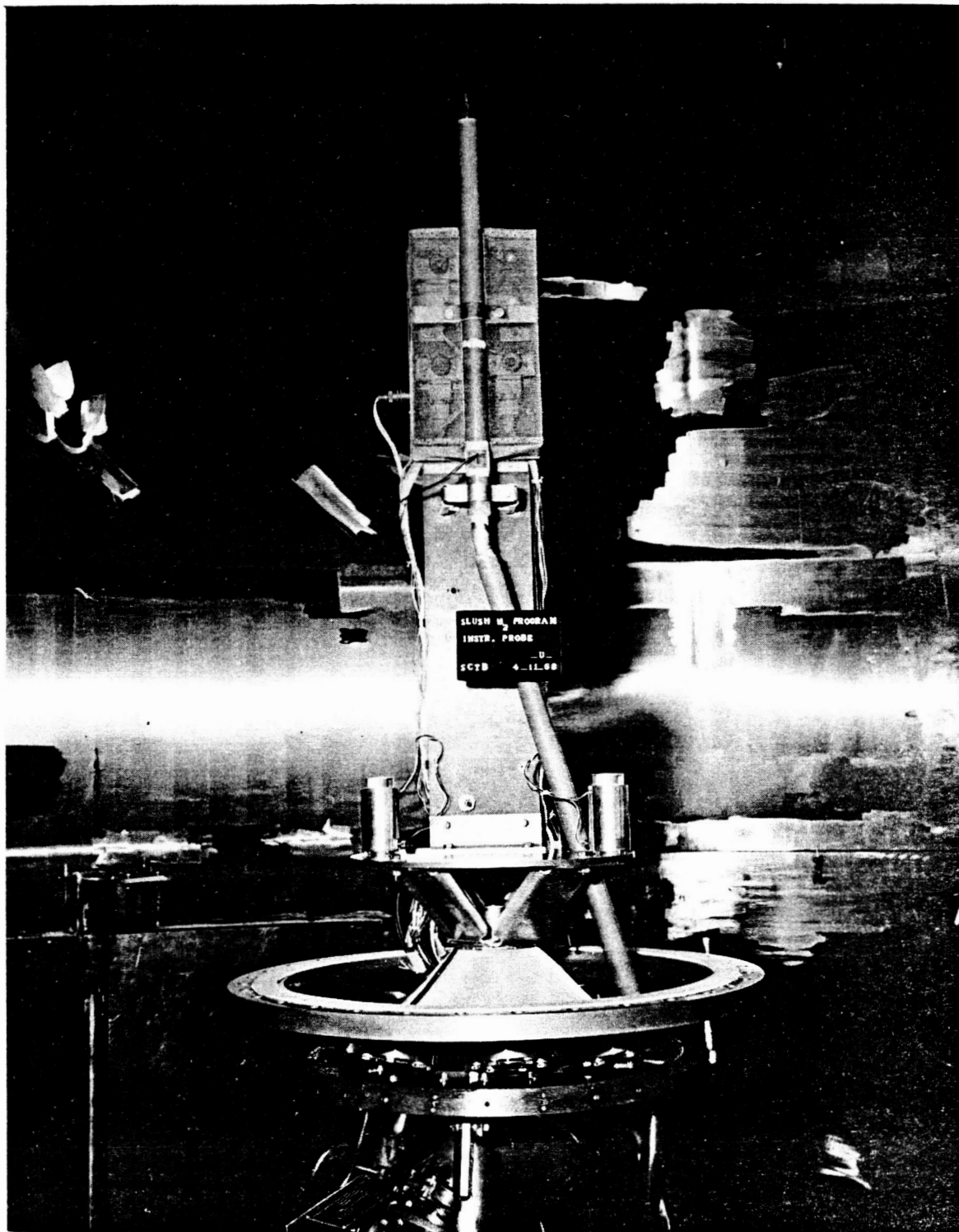


Fig. 2-12 Photograph of Completed Slush Test Tank Instrumentation and In-Tank Plumbing

## 2.2 PART B. S-IVC MANNED MARS FLYBY STUDY

During this quarterly reporting period, all remaining subsystem analyses and a comparison of vehicle performance were completed considering use of  $\text{LH}_2$  initially saturated at 16.2 psia, triple-point  $\text{LH}_2$ , and 50-percent slush  $\text{H}_2$ . Table 2-1 summarizes the major results of this analytical work. A draft of the final report for this vehicle study is being prepared for immediate submittal. Highlights of the work performed during the study are summarized in the following paragraphs.

### 2.2.1 Subsystem Analyses

Optimal insulation thicknesses for the cylindrical sidewall and the common bulkhead for the hydrogen tank of each S-IVC stage were determined independently by calculating and plotting effective payload penalties (the sum of insulation and equivalent boiloff weights) as functions of insulation thicknesses. The resulting optimal thicknesses are summarized in Table 2-1.

Predicted heat transfer time histories were then developed for the hydrogen tank of each stage and subsequently used in pressurization and venting subsystem analyses. Figures 2-13 through 2-15 show hydrogen tank pressure-time histories for the S-IVC<sub>1</sub> stage fueled with hydrogen at the three initial conditions of interest. These pressure histories are typical of those for the other S-IVC stages that are assembled in the orbital launch vehicle.

A summary of hydrogen tank venting histories is presented in Table 2-2. These data show that although use of subcooled hydrogen greatly reduces the resulting boiloff weights, hydrogen venting can be completely eliminated only for the S-IVC<sub>3</sub> stage which has a significantly shorter earth orbit storage period.

Pressurization gas and hardware weight requirements were determined for use of three initial hydrogen conditions in each S-IVC stage. These weights are summarized in Table 2-3. Cold helium from a ground facility source was assumed

Table 2-1  
SUMMARY OF S-IV C MANNED MARS FLYBY VEHICLE APPLICATION STUDY RESULTS

Initial Hydrogen Condition	LH <sub>2</sub> Sat. at 11.2 N/cm <sup>2</sup> (16.2 psia)		LH <sub>2</sub> Sat. at Triple Point		50% Liquid-Solid Mixture	
S-IV C <sub>1</sub> Stage (707-hr Orbital Storage):						
Gross Earth-Launch Weight, kg (lb)	121,111	(267,000)	121,111	(276,000)	121,111	(267,000)
Total Tanked Propellant Weight, kg (lb)	95,254	(209,995)	95,215	(209,910)	95,037	(209,518)
Total Tanked Hydrogen Weight, kg (lb)	19,736	(43,510)	21,241	(46,828)	20,124	(44,364)
Optimum Main Stage Mixture Ratio, O/H by Weight	5.5		4.2		4.2	
Optimum H <sub>2</sub> Tank Sidewall Insulation Thickness, cm (in.)	6.35	(2.5)	6.35	(2.5)	6.35	(2.5)
Optimum Common Bulkhead Insulation Thickness, cm (in.)	15.2	(6.0)	15.2	(6.0)	15.2	(6.0)
Total Hydrogen Vented in Earth Orbit, kg (lb)	3,676	(8,104)	1,486	(3,277)	145	(320)
S-IV C <sub>2</sub> Stage (696-hr Orbital Storage):						
Gross Earth-Launch Weight, kg (lb)	119,969	(264,482)	121,111	(267,000)	121,111	(267,000)
Total Tanked Propellant Weight, kg (lb)	94,260	(207,849)	95,385	(210,285)	95,268	(210,027)
Total Tanked Hydrogen Weight, kg (lb)	19,877	(43,820)	21,508	(47,416)	20,699	(45,832)
Optimum Main Stage Mixture Ratio, O/H by Weight	5.5		4.2		4.2	
Optimum H <sub>2</sub> Tank Sidewall Insulation Thickness, cm (in.)	6.35	(2.5)	6.35	(2.5)	6.35	(2.5)
Optimum Common Bulkhead Insulation Thickness, cm (in.)	8.89	(3.5)	8.89	(3.5)	8.89	(3.5)
Total Hydrogen Vented in Earth Orbit, kg (lb)	3,906	(8,611)	1,677	(3,696)	703	(1,549)
S-IV C <sub>3</sub> Stage (62-hr Orbital Storage):						
Gross Earth-Launch Weight, kg (lb)	121,111	(267,000)	121,111	(267,000)	121,111	(267,000)
Total Tanked Propellant Weight, kg (lb)	98,010	(216,072)	98,124	(216,323)	98,037	(216,130)
Total Tanked Hydrogen Weight, kg (lb)	19,777	(43,800)	20,775	(45,801)	20,759	(45,764)
Optimum Main Stage Mixture Ratio, O/H by Weight	4.764		4.2		4.2	
Optimum H <sub>2</sub> Tank Sidewall Insulation Thickness, cm (in.)	3.81	(1.5)	2.54	(1.0)	2.54	(1.0)
Optimum Common Bulkhead Insulation Thickness, cm (in.)	0		0		0	
Total Hydrogen Vented in Earth Orbit, kg (lb)	993	(2,189)	0		0	
Orbital Launch Vehicle (1975 Mars Twilight Mission):						
Gross Assembled Orbital Launch Weight, kg (lb)	392,106	(864,431)	404,726	(892,253)	407,320	(897,971)
Payload Spacecraft Weight, kg (lb)	81,920	(180,600)	87,205	(192,250)	87,749	(193,450)
Increase in Payload Weight %	0 (ref)		5,285	(11,650)	5,829	(12,850)
	0 (ref)		6.45		7.12	

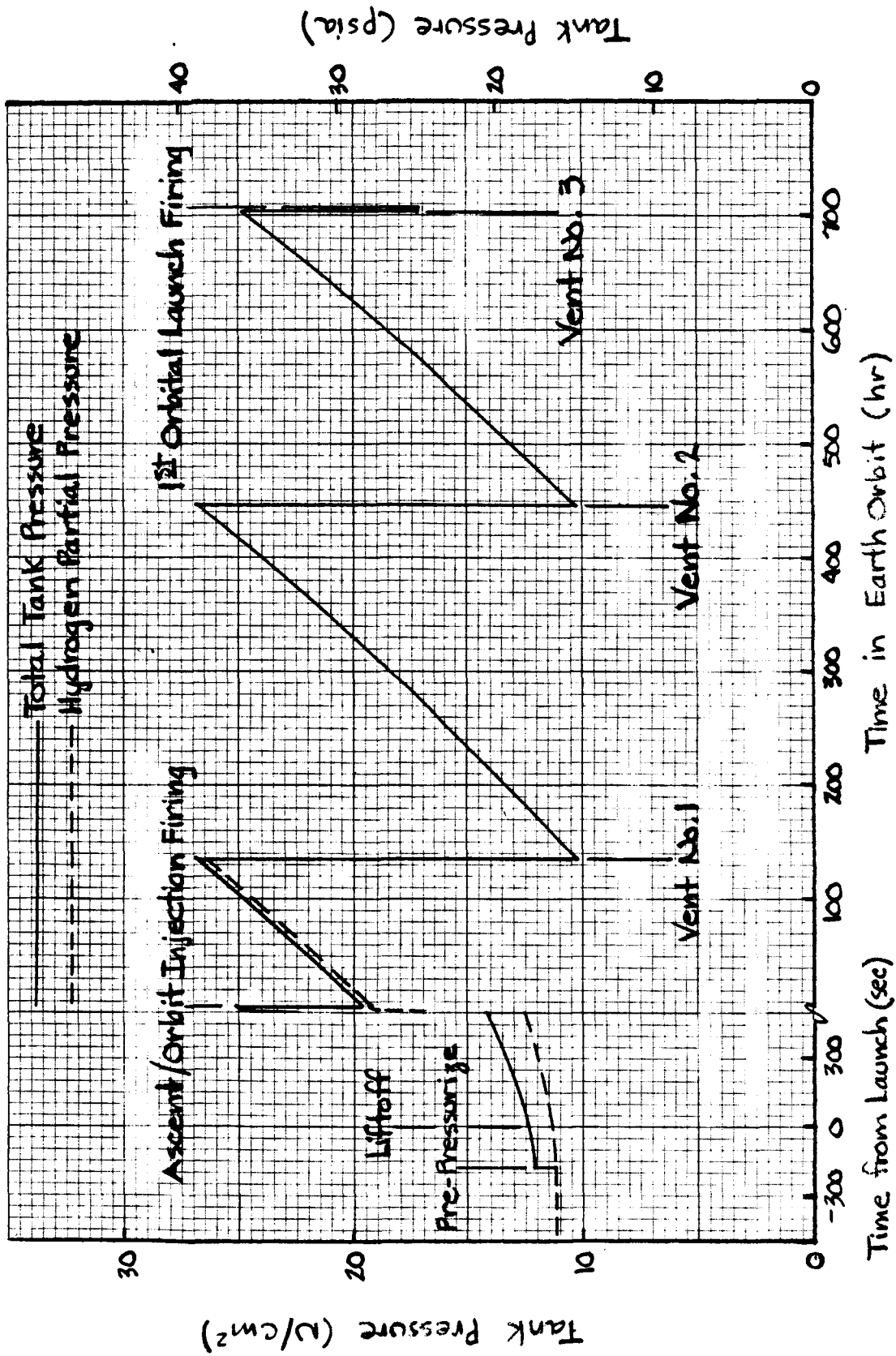


Fig. 2-13 Hydrogen Tank Pressure-Time History for S-IV C1 Stage Fueled With LH<sub>2</sub> Initially Saturated at 11.2 N/cm<sup>2</sup> (16.2 psia)

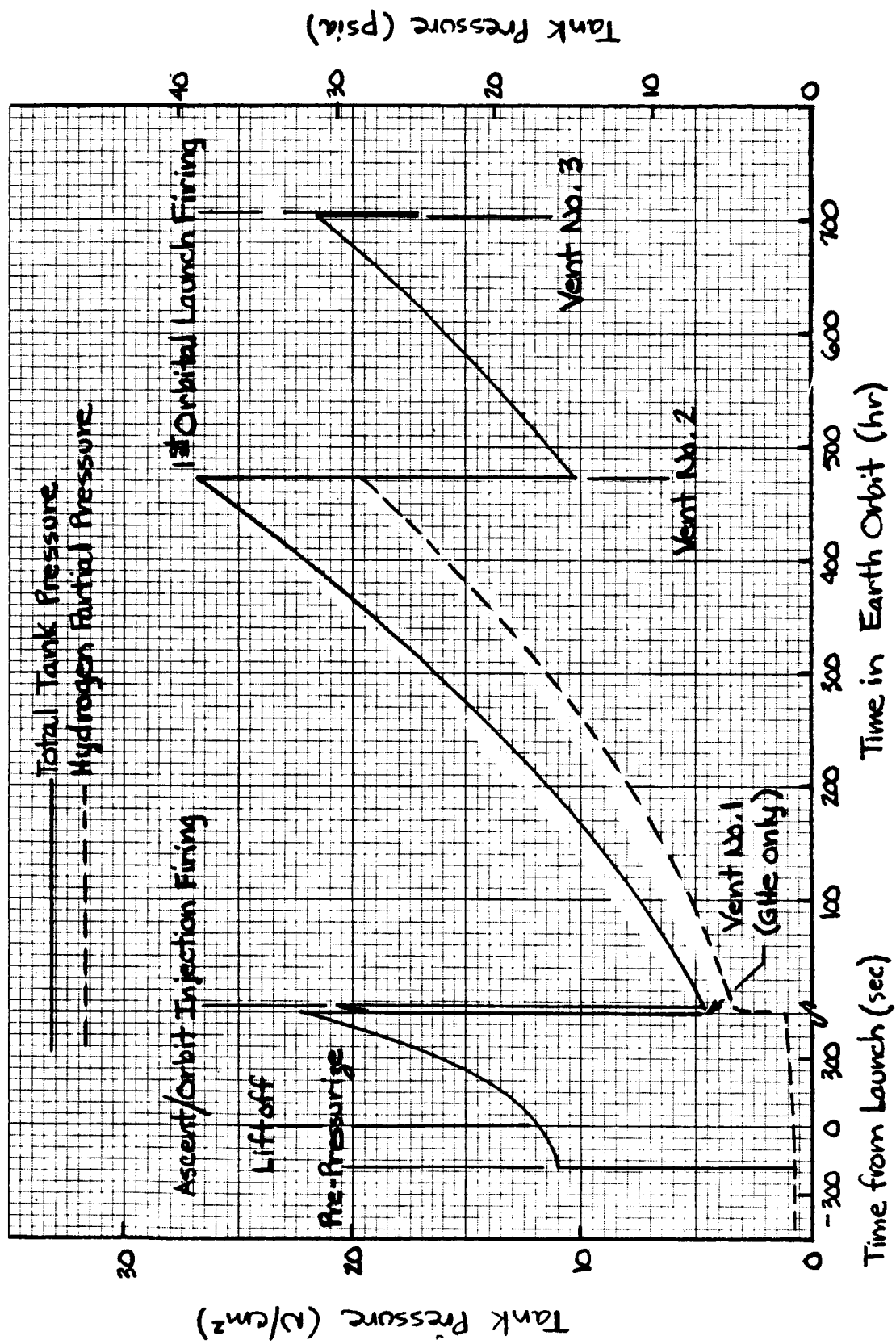


Fig. 2-14 Hydrogen Tank Pressure-Time History for S-IV C<sub>1</sub> Stage Fueled With LH<sub>2</sub> Initially Saturated at the Triple Point

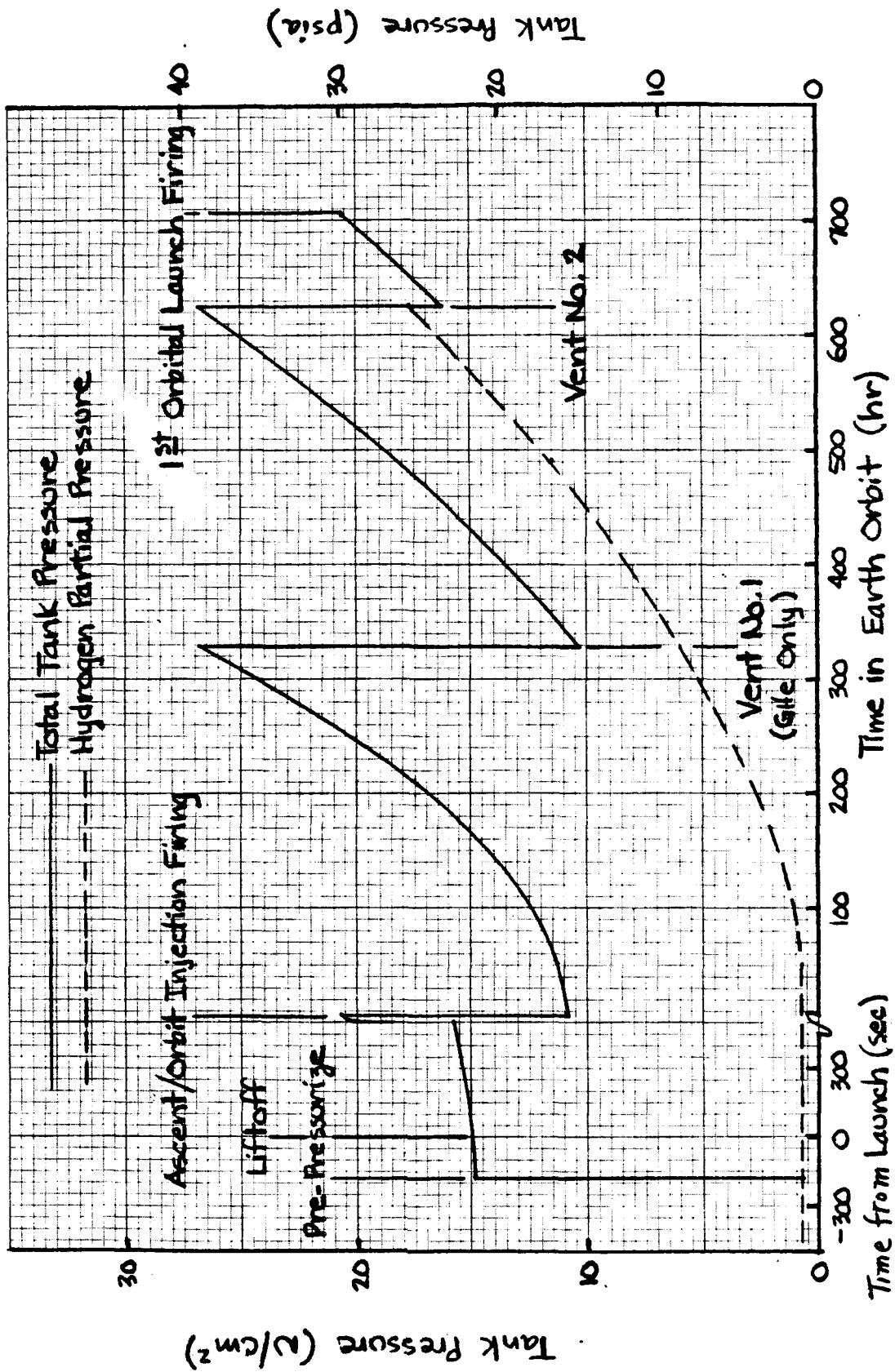


Fig. 2-15 Hydrogen Tank Pressure-Time History for S-IV C1 Stage Fueled With Initially 50-Percent Slush Hydrogen

Table 2-2  
SUMMARY OF HYDROGEN TANK VENTING HISTORY

Stage	Initial Hydrogen Condition	Vent No.	Time of Vent (hr) <sup>A</sup>	Mass of H <sub>2</sub> Vented, kg (lb)	
S-IV C <sub>1</sub>	LH <sub>2</sub> Sat. at 11.2 N/cm <sup>2</sup> (16.2 psia)	1	70.6	1,551	(3,420)
		2	304.1	1,491	(3,288)
		3	707.0	<u>633</u>	<u>(1,396)</u>
		Total		3,675	(8,104)
	LH <sub>2</sub> Sat. at T. P.	1	366.1	1,052	(2,320)
		2	707.0	<u>434</u>	<u>(957)</u>
		Total		1,486	(3,277)
	50 Percent Liquid-Solid Mixture	1	230.3	Negl. <sup>B</sup>	
		2	623.7	<u>145</u>	<u>(320)</u>
		Total		145	(320)
S-IV C <sub>2</sub>	LH <sub>2</sub> Sat. at 11.2 N/cm <sup>2</sup> (16.2 psia)	1	74.0	1,551	(3,420)
		2	278.1	1,505	(3,318)
		3	672.4	<u>850</u>	<u>(1,873)</u>
		Total		3,906	(8,611)
	LH <sub>2</sub> Sat. at T. P.	1	334.3	1,043	(2,300)
		2	683.0	<u>633</u>	<u>(1,396)</u>
		Total		1,676	(3,696)
	50 Percent Liquid-Solid Mixture	1	213.4	Negl. <sup>B</sup>	
		2	450.5	<u>703</u>	<u>(1,549)</u>
		Total		703	(1,549)
S-IV C <sub>3</sub>	LH <sub>2</sub> Sat. at 11.2 N/cm <sup>2</sup> (16.2 psia)	1	6.0	280	(617)
		2	62.0	<u>713</u>	<u>(1,572)</u>
		Total		993	(2,189)
	LH <sub>2</sub> Sat. at T. P.	-	-	0	
	50 Percent Liquid-Solid Mixture	-	-	0	

NOTES:

<sup>A</sup> Time from liftoff of each particular stage.<sup>B</sup> Initial vent programmed to blowdown partial pressure of GHe prepressurant; vent terminates at a pressure above H<sub>2</sub> saturation pressure with negligible loss of hydrogen.

Table 2-3  
SUMMARY OF PRESSURIZATION WEIGHT REQUIREMENTS

Pressurization Function	Initial Hydrogen Condition							
	LH <sub>2</sub> Sat. at 11.2 N/cm <sup>2</sup> (16.2 psia)				LH <sub>2</sub> Sat. at T. P.			
	Pressurant Wt kg (lb)	Hardware Wt kg (lb)	Mode	Pressurant Wt kg (lb)	Hardware Wt kg (lb)	Mode	Pressurant Wt kg (lb)	Hardware Wt kg (lb)
<b>S-IV C<sub>1</sub> Stage:</b>								
Prepressurization	2.7 (5.9)	0	A	51.3 (113.1)	0	B	197.2 (434.8)	0
Expulsion for Ascent Firing	25.4 (56.1)	0	D	19.3 (42.6)	0	D	18.6 (40.9)	0
Repressurization	22.1 (48.8)	33.2 (73.2)	C	7.8 (17.2)	11.7 (25.8)	C	4.9 (10.9)	7.4 (16.4)
Expulsion for 1st OLV Firing	143.5 (316.4)	0	D	186.4 (411.0)	0	D	223.8 (493.4)	0
CH <sub>4</sub>	24.8 (54.7)			59.1 (130.3)			202.1 (445.7)	
CH <sub>2</sub>	168.9 (372.5)			205.7 (453.6)			242.4 (534.3)	
Totals		33.2 (73.2)			11.7 (25.8)			7.4 (16.4)
<b>S-IV C<sub>2</sub> Stage:</b>								
Prepressurization	4.5 (10.0)	0	A	51.8 (114.1)	0	B	187.9 (414.3)	0
Expulsion for Ascent Firing	25.4 (55.9)	0	D	19.3 (42.6)	0	D	18.6 (40.9)	0
Repressurization	23.3 (51.4)	35.0 (77.1)	C	8.4 (18.6)	12.6 (27.9)	C	5.7 (12.5)	8.6 (18.8)
Expulsion for 2nd OLV Firing	35.5 (78.3)	0	D	48.7 (107.2)	0	D	48.6 (107.2)	0
Repressurization	30.8 (67.9)	46.2 (101.9)	C	21.9 (48.3)	32.9 (72.5)	C	20.9 (46.0)	31.4 (69.0)
Expulsion for 3rd OLV Firing	108.5 (239.1)	0	D	141.5 (312.0)	0	D	146.4 (322.9)	0
CH <sub>4</sub>	58.6 (129.3)			82.1 (181.0)			214.5 (472.8)	
CH <sub>2</sub>	169.4 (373.3)			207.5 (457.5)			213.6 (470.9)	
Totals		81.2 (179.0)			45.5 (100.4)			40.0 (87.8)
<b>S-IV C<sub>3</sub> Stage:</b>								
Prepressurization	2.6 (5.8)		C	109.2 (240.8)	0	B	164.7 (363.2)	0
Expulsion for Ascent Firing	27.0 (59.5)	0	D	25.8 (56.9)	0	D	19.1 (42.1)	0
Repressurization	13.9 (30.7)	20.9 (46.1)	C	6.8 (15.1)	10.2 (22.7)	C	13.7 (30.2)	20.6 (45.3)
Expulsion for 4th OLV Firing	173.0 (381.5)	0	D	170.1 (375.0)	0	D	163.3 (359.9)	0
CH <sub>4</sub>	16.5 (36.5)			116.0 (255.9)			178.4 (393.4)	
CH <sub>2</sub>	200.0 (441.0)			195.9 (431.9)			182.4 (402.0)	
Totals		20.9 (46.1)			10.2 (22.7)			20.6 (45.3)

Modes of Pressurization:

- A Ground facility helium at 20.7°K (37.2°R).  
 B Ground facility helium at 13.8°K (24.9°R).  
 C Helium stored in spherical bottles at LH<sub>2</sub> temp., heated to 138.9°K (250°R) with gas burner,  $M/M_{reqd} = 2.5$ .  
 D GH<sub>2</sub> engine bleed at 111°K (200°R).

for pre-pressurization prior to launch, cryogenically stored helium heated with an  $O_2-H_2$  burner was assumed for in-flight repressurization requirements, and warm hydrogen bleed from the engine was assumed for expulsion requirements. It is interesting to note that for this particular vehicle, which requires storage of most of the propellant for use at the end of the storage period, pressurization weight requirements are actually less where subcooled hydrogen is used rather than atmospheric-saturated hydrogen. This effect is opposite to that observed in the previous S-IVB/LASS study where the propellant utilization schedule was significantly different in that more firings were required, with use of a substantial portion of the propellant early in the mission.

#### 2.2.2 Performance Comparison

Significant results of the performance comparison obtained from this study are presented in Table 2-1. The estimated dry-stage inert weights used in the analysis are summarized in Table 2-4, while a summary of the actual performance weights obtained from the analysis is presented in Table 2-5. It can be seen by inspection of these data that performance gains achieved with use of subcooled and slush hydrogen for this vehicle/mission combination, though substantial, are not as great as those determined for the S-IVB/LASS vehicles previously studied. This can be attributed to two significant differences. These are: (1) the use of high-performance insulation and other improvements to reduce heat transfer results in improved storability of atmospheric-saturated  $LH_2$  for the S-IVC stages, and (2) no substantial off-loading of propellants due to hydrogen tank volume constraints resulted from use of atmospheric-saturated  $LH_2$ , as did occur with the S-IVB/LASS vehicle.

Table 2-4  
ESTIMATED DRY-STAGE INERT WEIGHTS

Item Description	Ref. Source	LH <sub>2</sub> Sat. at 11.2 N/cm <sup>2</sup> (16.2 psia) kg (lb)	LH <sub>2</sub> Sat. at Triple Point lb (lb)	50% Liquid-Solid Mixture N/cm <sup>2</sup> (16.2 psia) lb (lb)
Dry Stage (SA 504 and subsequent) Removed:	Douglas Report DAC-57997	11,284 (24,876)	Same as for LH <sub>2</sub> Sat. at 11.2 N/cm <sup>2</sup> (16.2 psia)	Same as for LH <sub>2</sub> Sat. at 11.2 N/cm <sup>2</sup> (16.2 psia)
Batteries and Mounts		-376 (-830)		
APS Modules		-388 (-855)		
Ullage Rockets		-91 (-200)		
Chilldown and Purge Systems		-130 (-287)		
Miscellaneous Engine Systems		-22 (-48)		
Internal Insulation		-629 (-1,386)		
Add Common Structure and Equipment Modifications:				
Aft Skirt APS Modifications		+36 (+80)		
J-2S Engine		-112 (-246)		
Forward Heat Block		+106 (+233)		
Power System		+1,557 (+3,432)		
Common Dome Heat Block		+12 (+26)		
Forward Docking Structure		+772 (+1,702)		
Aft Docking Structure		+604 (+1,332)		
Forward Dome External Insulation		+34 (+74)		
Aft Dome Insulation		+4 (+9)		
Common-Modification Dry-Stage Weight		12,661 (27,912)	12,661 (27,912)	12,661 (27,912)
Add S-IVC <sub>1</sub> Modifications:	Present Lockheed Study			
External Insulation and Meteoroid Bumper		+885 (+1,950)	+885 (+1,950)	+885 (+1,950)
Common Bulkhead Insulation		+653 (+1,440)	+653 (+1,440)	+653 (+1,440)
Additional Instrumentation and Wiring		0	+9 (+20)	+41 (+90)
Liquid-Return Line, Valve, and Disconnect		0	+32 (+70)	+32 (+70)
Hydrogen Tank Pressurization System Reqs.		-65 (-144)	-98 (-216)	-98 (-216)
Total Modified S-IVC <sub>1</sub> Dry-Stage Weight		14,134 (31,156)	14,142 (31,176)	14,174 (31,246)
Add S-IVC <sub>2</sub> Modifications:				
External Insulation and Meteoroid Bumper		+885 (+1,950)	+885 (+1,950)	+885 (+1,950)
Common Bulkhead Insulation		+381 (+840)	+381 (+840)	+381 (+840)
Additional Instrumentation and Wiring		0	+9 (+20)	+41 (+90)
Liquid-Return Line, Valve, and Disconnect		0	+32 (+70)	+32 (+70)
Hydrogen Tank Pressurization System Reqs.		0	-33 (-72)	-65 (-144)
Total Modified S-IVC <sub>2</sub> Dry-Stage Weight		13,327 (30,702)	13,335 (30,720)	13,335 (30,718)
Add S-IVC <sub>3</sub> Modifications:				
External Insulation and Meteoroid Bumper		+599 (+1,321)	+473 (+1,043)	+473 (+1,043)
Common Bulkhead Insulation		+87 (+192)	0	0
Additional Instrumentation and Wiring		0	+9 (+20)	+41 (+90)
Liquid-Return Line, Valve, and Disconnect		0	+32 (+70)	+32 (+70)
Hydrogen Tank Pressurization System Reqs.		-65 (-144)	-98 (-216)	-98 (-216)
Total Modified S-IVC <sub>3</sub> Dry-Stage Weight		13,282 (29,281)	13,077 (28,829)	13,109 (28,899)

Table 2-5  
SUMMARY OF PERFORMANCE WEIGHTS

Weight Description	Initial Hydrogen Condition						50 Percent Liquid-Solid Mixture					
	LH <sub>2</sub> Sat. at 11.2 N/cm <sup>2</sup> (16.2 psia)			LH <sub>2</sub> Sat. at T. P.			S-IV C <sub>1</sub>			S-IV C <sub>2</sub>		
	S-IV C <sub>1</sub> kg (lb)	S-IV C <sub>2</sub> kg (lb)	Total kg (lb)	S-IV C <sub>1</sub> kg (lb)	S-IV C <sub>2</sub> kg (lb)	Total kg (lb)	S-IV C <sub>1</sub> kg (lb)	S-IV C <sub>2</sub> kg (lb)	Total kg (lb)	S-IV C <sub>1</sub> kg (lb)	S-IV C <sub>2</sub> kg (lb)	Total kg (lb)
Gross Earth-Launch Weight	121,111 (267,000)	119,969 (264,482)	241,080 (531,482)	121,111 (267,000)	121,111 (267,000)	242,222 (534,000)	121,111 (267,000)	121,111 (267,000)	242,222 (534,000)	121,111 (267,000)	121,111 (267,000)	242,222 (534,000)
Less Weight Jettisoned in Earth Orbit	19,179 (42,281)	19,356 (42,672)	38,535 (84,953)	19,179 (42,281)	19,356 (42,672)	38,535 (84,953)	19,179 (42,281)	19,356 (42,672)	38,535 (84,953)	19,179 (42,281)	19,356 (42,672)	38,535 (84,953)
Plus Payload Spacecraft Weight			81,920 (180,600)			81,920 (180,600)			81,920 (180,600)			81,920 (180,600)
Gross Orbital Launch Weight			392,105 (864,431)			392,105 (864,431)			392,105 (864,431)			392,105 (864,431)
Less Transients and Settling Propellant Weight	459 (1,013)		459 (1,013)	459 (1,013)		459 (1,013)	459 (1,013)		459 (1,013)	459 (1,013)		459 (1,013)
First OLV Firing Initial Weight			391,646 (863,418)			391,646 (863,418)			391,646 (863,418)			391,646 (863,418)
Less 1st OLV Firing Impulse Propellant Weight	83,394 (183,850)		83,394 (183,850)	83,394 (183,850)		83,394 (183,850)	83,394 (183,850)		83,394 (183,850)	83,394 (183,850)		83,394 (183,850)
First OLV Firing Burnout Weight			308,252 (679,568)			308,252 (679,568)			308,252 (679,568)			308,252 (679,568)
Less Jettisoned Weights	18,079 (39,856)	459 (1,013)	18,538 (40,869)	18,079 (39,856)	459 (1,013)	18,538 (40,869)	18,079 (39,856)	459 (1,013)	18,538 (40,869)	18,079 (39,856)	459 (1,013)	18,538 (40,869)
Second OLV Firing Initial Weight			289,714 (638,599)			289,714 (638,599)			289,714 (638,599)			289,714 (638,599)
Less 2nd OLV Firing Impulse Propellant Weight	20,446 (45,076)		20,446 (45,076)	20,446 (45,076)		20,446 (45,076)	20,446 (45,076)		20,446 (45,076)	20,446 (45,076)		20,446 (45,076)
Second OLV Firing Burnout Weight			269,268 (593,623)			269,268 (593,623)			269,268 (593,623)			269,268 (593,623)
Less Transients and Settling Propellant Weight	459 (1,013)		459 (1,013)	459 (1,013)		459 (1,013)	459 (1,013)		459 (1,013)	459 (1,013)		459 (1,013)
Third OLV Firing Initial Weight			268,809 (592,610)			268,809 (592,610)			268,809 (592,610)			268,809 (592,610)
Less 3rd OLV Firing Impulse Propellant Weight	61,339 (135,228)		61,339 (135,228)	61,339 (135,228)		61,339 (135,228)	61,339 (135,228)		61,339 (135,228)	61,339 (135,228)		61,339 (135,228)
Third OLV Firing Burnout Weight			207,470 (457,352)			207,470 (457,352)			207,470 (457,352)			207,470 (457,352)
Less Jettisoned Weights	17,310 (38,480)	459 (1,013)	17,769 (39,493)	17,310 (38,480)	459 (1,013)	17,769 (39,493)	17,310 (38,480)	459 (1,013)	17,769 (39,493)	17,310 (38,480)	459 (1,013)	17,769 (39,493)
Fourth OLV Firing Initial Weight			189,101 (416,889)			189,101 (416,889)			189,101 (416,889)			189,101 (416,889)
Less 4th OLV Firing Impulse Propellant Weight	89,956 (198,316)		89,956 (198,316)	89,956 (198,316)		89,956 (198,316)	89,956 (198,316)		89,956 (198,316)	89,956 (198,316)		89,956 (198,316)
Fourth OLV Firing Burnout Weight			99,145 (218,573)			99,145 (218,573)			99,145 (218,573)			99,145 (218,573)
Less S-IV C <sub>3</sub> Burnout Weight	17,225 (37,973)		17,225 (37,973)	17,225 (37,973)		17,225 (37,973)	17,225 (37,973)		17,225 (37,973)	17,225 (37,973)		17,225 (37,973)
Spacecraft Payload Weight			81,920A (180,600)			81,920A (180,600)			81,920A (180,600)			81,920A (180,600)
Increase in Spacecraft Payload Weight			5,284 (11,660)			5,284 (11,660)			5,284 (11,660)			5,284 (11,660)
			17,155 (37,823)			17,155 (37,823)			17,155 (37,823)			17,155 (37,823)

A Reference case.